A Dual Band Telescope for Microwave Instrument on Rosetta Orbiter (MIRO)[1]

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Abstract—In this paper the requirements, specifications, design procedures, and analytical results for a dual frequency space-based telescope are discussed. The telescope is used as part of the microwave instrument on board the Rosetta Orbiter spacecraft, which will be launched early in the next century to rendezvous with and probe the Comet Wirtanen for water content and other material properties. The Offset-fed Cassegrain telescope reaches two receivers at millimeter (190 GHz) and sub-millimeter (560 GHz) via a beam waveguide arrangement. Gaussian beam and Physical Optics methods have been used in the successful design and analysis of the telescope. The telescope provides far field patterns with good efficiency better than 60%, and very low sidelobes better than 30 dB. RF properties of the telescope at varying temperatures, mechanical tolerances, and other operational situations are discussed.

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1. INTRODUCTION

The Jet Propulsion Laboratory (JPL) is currently designing and building a number of instruments that operate in the microwave, millimeter, and sub-millimeter-wave frequency bands. A prominent one is the Microwave Instrument for the Rosetta Orbiter (MIRO) for the study of the comet Wirtanen. The planned Rosetta Orbiter spacecraft will rendezvous with the comet early next century and drop the Champollion lander.

MIRO is an instrument, which will be used to measure the surface temperature gradient as a function of comet position; measure the out-gassing of water, ammonia, carbon monoxide, and other gasses; and the temperature of the gasses in the coma. MIRO will help us understand how the solar system was formed, because comets are samples of material left over from that period. MIRO is being developed by an international consortium comprised of JPL in the USA, the Observatoire de Paris in France, and the Max Planck Institut fur Aeronomie (MPAe) in Germany [1].

At the heart of this instrument is a dual-frequency receiving reflector antenna or telescope. The MIRO telescope is used to receive data from the surface of the comet for detecting presence of organic materials, primarily water, at 190 GHz (1.58-mm wavelength) and 564 GHz (0.54-mm wavelength).

One of the primary requirements for the telescope is the achievement of very low sidelobe beams (better than 30 dB) at both frequencies while maintaining good efficiency and minimizing noise levels at the receivers. This requires highly polished surfaces, which must be maintained throughout the subsystem and over the spacecraft life.

The challenge is to maintain these low sidelobe levels subject to the thermal distortion and mechanical vibration along the orbit during the operational phase. Of particular concern is the effect of thermal variations on the telescope mirrors in the 100 to 300 degrees Kelvin range.

In this paper a somewhat detailed description of the optical system will be given, and some preliminary theoretical and simulated performance data and beam patterns at both frequencies will be presented. The effect of thermal and mechanical tolerances on the critical performance parameters will be discussed.

2. OPTICAL PRESCRIPTION

The designed telescope is a beam-waveguide fed offset Cassegrain system. As shown in Figure 1, the sub-reflector and main or primary reflector are on a platform outside the spacecraft. The received beam are focused on the receivers which are located on an optical bench below the platform, as shown in Figure 2, via a circular hole on the platform and a set of small mirrors that guide the beam.

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The parabolic primary reflector has a diameter of 300 millimeters. The Hyperbolic secondary has a diameter of 90 millimeters. Separate receivers are used for the millimeter and sub-millimeter frequencies. The main electrical parameters are specified below:

Telescope

Beam waveguide offset-fed Cassegrain reflector system
Main reflector diameter: 300 mm
Minimum sidelobe level < 30 dB from peak

Millimeter receiver

Freq.: 190 GHz
Wavelength: 1.5779 mm
Polarization: linear
Approximate 3-dB Beamwidth:
$\theta_{hp} = 70.5/(D/\lambda) = 0.37$ Deg = 22 arc min

Sub-millimeter receiver

Freq. 564 GHz
Wavelength: .5315 mm
Polarization: linear
Approximate 3-dB Beamwidth:
$\theta_{hp} = 70/(D/\lambda) = 0.125$ Deg = 7.5 arc min

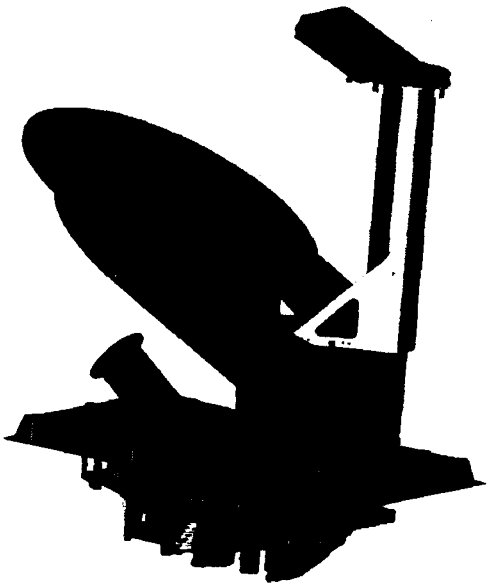

Figure 1 A Pro Engineer Layout of the MIRO telescope

As shown in Figure 2, the receivers, located an on optical bench inside the instrument, receive the incoming waves via a beam wave-guiding system, consisting of a number of smaller mirrors that direct the incoming field from the primary and secondary mirrors to the receivers.

Figure 3 presents a schematic of the overall optical system of the telescope including the side and top views of the optical bench.. A turning mirror is used to direct the fields to the optical bench region. A flat polarizer grid on the optical path is then used to separate the fields at the two frequencies. Thus a linearly polarized filed at millimeter frequency is transmitted through the grid while the sub-millimeter wave is reflected at the orthogonal polarization.

The separated frequencies are then directed to their respective receiving horns via so-called matching mirrors. The millimeter horn is a corrugated circular horn [2], while the sub-millimeter horn is a smooth-walled picket horn [3]. This optical arrangement is optimized for both frequencies.

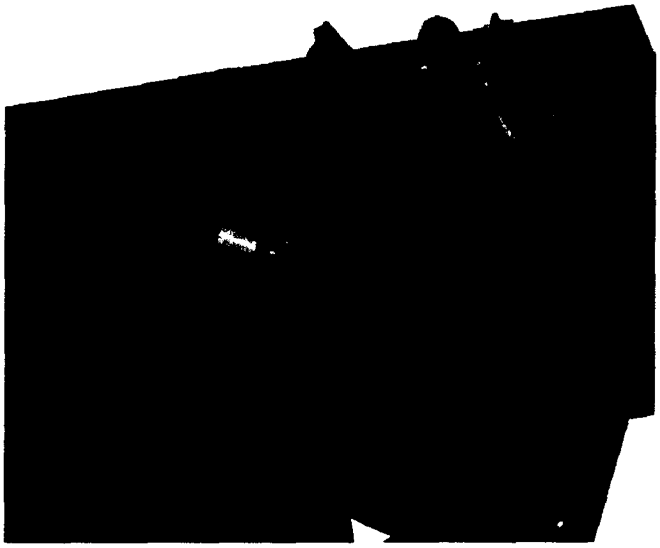

Figure 2 A Pro-Engineer Layout of the MIRO optical bench

3. Design Procedure

The beam waveguide system used in the telescope design has the following advantages: i- Much lower loss compared to standard waveguides, namely a few tenth dB as opposed to a few dB, specially at high millimeter and sub-millimeter frequencies, ii- Wider bandwidth (multi-frequency) capability, iii- Easy integration of many feeds at different frequencies and locations. However, it has the following disadvantages: i- It is relatively more costly than conventional waveguides, ii- It is subject to interference if not shielded, iii- When used in space, mechanical vibration and thermal distortions become critical factors and must be carefully considered and limited.

A simple zero-order Gaussian beam analysis is used for the preliminary design of this beam waveguide system [4]. In this approach, each mirror is approximated by a thin lens of a specific focal length. The electromagnetic field is approximated by a simple Gaussian approximation.

In this approximation, the field has a peak value on the axis of symmetry and decays exponentially with the square of the distance away from the axis. Furthermore, it has a diverging wave-front along the axis Using this approximation, the field distribution at each mirror can be reasonably estimated and the size of each mirror can be evaluated to obtain a desired taper at the main or primary reflector. The design is subsequently refined by the application of the physical optics for accurate analysis of the performance of the optical system [5].

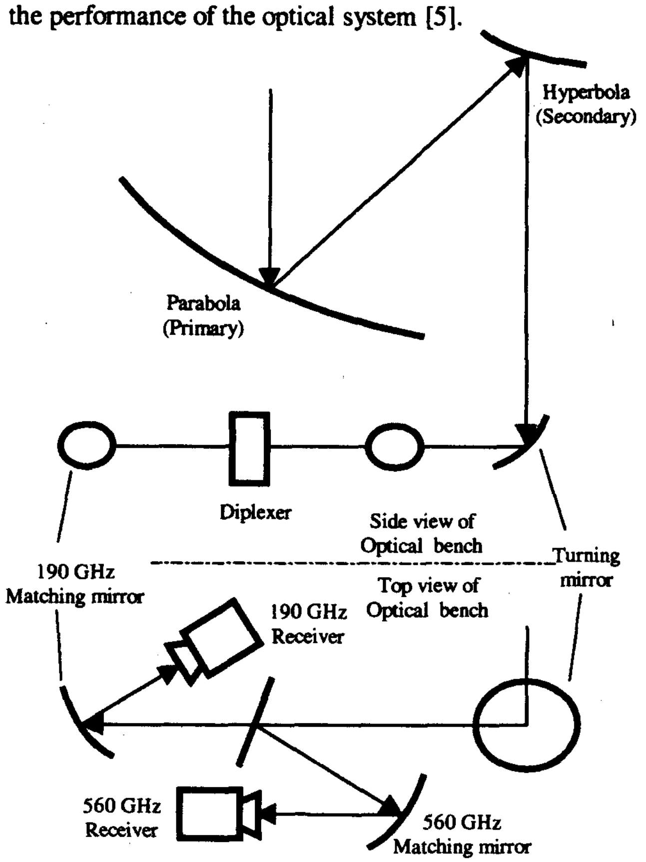

Figure 3. Schematic diagram of the optical system including the side and top views of the optical bench

An integrated and streamlined approach to the mechanical, thermal, and RF design and analysis is used, under the MODTool (Microwave Optics Design Tool) Task [6]. The methodology and software developed for this task will be used for all similar future spacecraft.

4. THEORETICAL ANALYSIS

Appropriate and accurate methods of analysis of the RF optical systems depend on the dimensions of the mirrors in terms of wavelength. In general, in the order given below, the accuracy increases but at the expense of increased computational complexity and time.

Geometrical optics (ray tracing) for $D > 50\lambda$

Gaussian beam analysis (approximate solutions of wave equation for waves confined near an optical axis for $20\lambda < D < 50\lambda$

Physical Optics analysis (involving calculation of currents on reflectors + fringe currents if needed) for $D < 20\lambda$

For MIRO optics, following an initial Gaussian-based design, all the optical elements of the system, including mirror and feed elements have been rigorously analyzed using the physical optics (PO) approach.

In this approach currents generated on each optical mirror by the feed horns are first calculated. Then these currents are integrated using the radiation integral, in order to obtain the fields and hence currents on the next mirror. Finally, the currents on the main or primary reflector are integrated to obtain the far field patterns of the system.

Figures 4-5 shows a sample far field pattern of the reflector system at the two main frequencies of interest. Four azimuthal cuts 90 degrees apart are superimposed in each figure. As can be seen, The sidelobe levels for both frequencies are well below 30 dB from the beam peak.

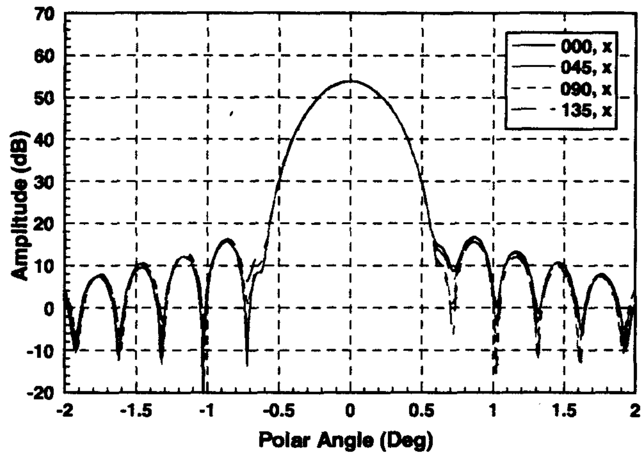

Figure 4. MIRO Telescope Radiation Patterns at 190 GHz

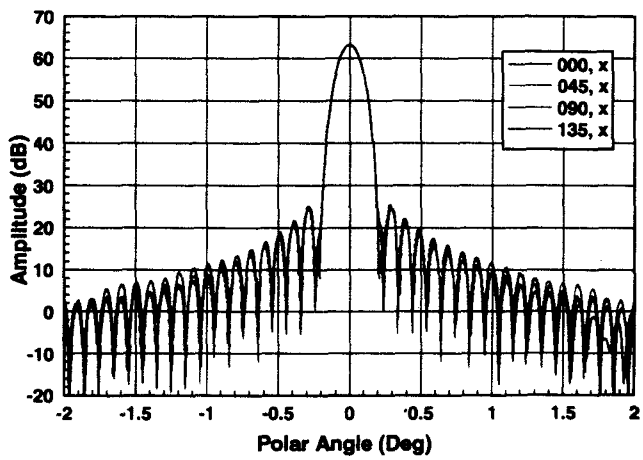

Figure 5. MIRO Telescope Radiation Patterns at 564 GHz

Approximate gain-loss budget allocations for the beam patterns are given in Table 1.

Table 1. Gain-loss budgets the dual reflector system at 190 and 560 GHz frequencies.

Frequency	190 GHz	564 GHz
Spillover	<0.1 dB	< 0.1 dB
Surface rms	< 0.1 dB	< 0.3 dB

Illumination	< 1.6 dB	< 1.5 dB
Total	< 1.8 dB	< 1.9 dB
Theoretical Peak Gain	55.52 dB	64.97 dB
Actual peak gain:	53.7 dB	63.0 dB
Efficiency:	66%	64%

5. THERMAL AND TOLERANCE STUDIES

One of the most critical aspects of the design of the optical system is its performance under various distortion effects. The primary indices of performance are the beam tilt from its nominal position, or beam pointing error, and the increase in sidelobe levels. Distortions can occurs primarily due to mechanical tolerances and the thermal effects.

Under extremes of temperature variations in space the variation in performance could become critical. Therefore, the design must be thoroughly tested for compliance with the specified requirements for beam pointing and sidelobe levels. The MIRO Telescope tolerance requirements are:

- to maintain the sidelobes at better than 30 dB level
- to keep the beam pointing error at no more than 1/10 the half-power beam-width.

Since the optical bench is in a thermally stable environment, the only area of concern is the mechanical tolerances, which have been thoroughly, investigated and will be published in a future article [8]. The primary and secondary reflectors and their pedestals, however, are outside the spacecraft and subjected to thermal variation.

Simulations have been performed to investigate the temperature profiles on the sub and main reflectors at various distances from the sun and at various angular positions.

Figure 6, shows a typical temperature profile on the upper platform. The effect of such non-uniform thermal distribution is the distortion of the surfaces as well as the support structures.

An exaggerated view of such distortions is shown in Figure 7. These distortions cause tilt, coma, sidelobe deterioration, etc., on the antenna patterns.

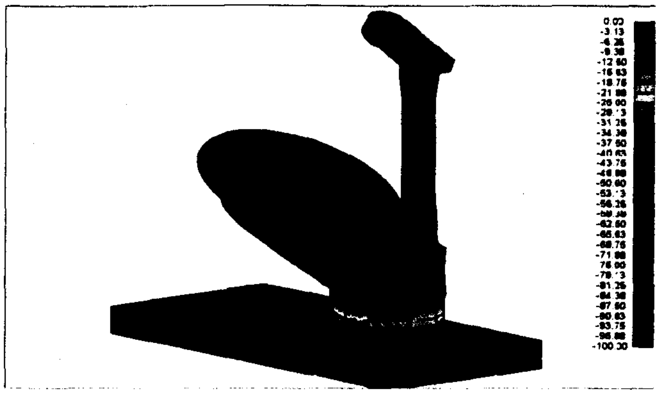

Figure 6. A color-coded temperature profile of the telescope mirrors

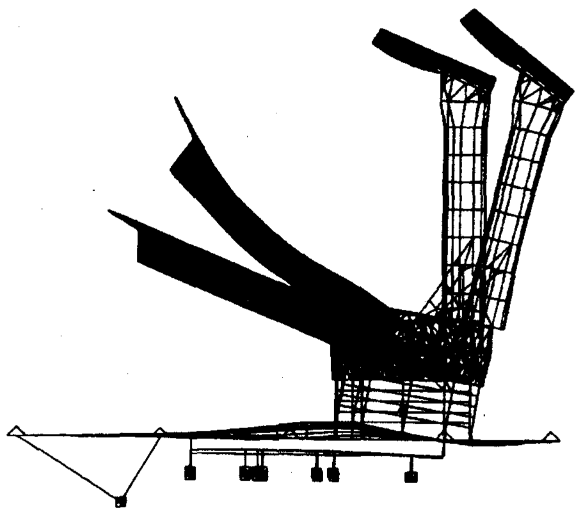

Figure 7. An exaggerated view of thermal distortion of the telescope mirrors and support structure

Figure 8 shows typical undistorted and distorted patterns due to thermal distortions of the secondary and primary reflectors. A complete analysis has been performed for many cases and will be separately published [8].

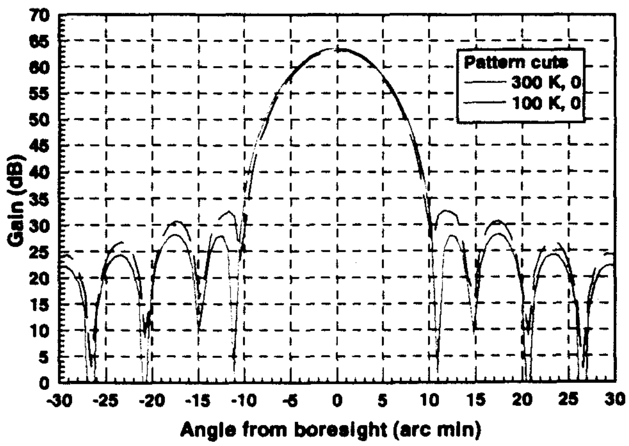

Figure 8. A comparison of the nominal and distorted radiation patterns of MIRO telescope (from 300° K to 100°

K) at 560 GHz.

4. Conclusions and Future Plans

In this paper we have outlined the salient features of a beam waveguide telescope for the MIRO project. It has been shown that a successful multi-frequency design can be obtained using Gaussian beam and physical optics analysis. Mechanical, thermal and RF simulations have been performed and show excellent agreement with the requirements. The system is presently under fabrication.

Following the fabrication and assembly, the performance of the system will be experimentally verified. Antenna measurement tests on outdoor ranges will not be acceptable due to the substantial losses in the uncontrollable humidity levels, since the frequencies of interest are on or near the absorption lines of water vapor. Therefore, the pattern measurements will be performed using an in-door near field measurement system in a controlled laboratory environment.

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